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Potential of biogas production in Iran

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ABSTRACT

Biomass is the only renewable energy source which can deliver electricity, provide heating, cooling and fuel in form of solid, liquid and gas. Biomass supplies more than 11.5% of the world's primary energy and about 79.7% of the world's energy consumption. In 2012, about 194.8 million ton of renewable energy was consumed in the world and about 0.1 million ton was consumed in Iran. Biogas is produced by anaerobic fermentation. Global biogas capacity will reach 22,000 MW by 2025. European biogas electricity production in 2006 was 17,272 GWh per year, of which 7338 GWh was by Germany alone. Biogas now represents 1.2% of the annual production of electricity and nearly 10% of renewable energy, with an installed power close to 1500 MW. Global biogas installed capacity is expected to achieve moderate growth over the next 12 years, reaching 22.040 MW by 2025 and making a compound annual growth rate (CAGR) of 7.2%, a recently published analysis by Global Information Inc (GII) showed. The world biogas market has grown considerably between 2001 and 2011, with installed capacity expanding to 8.377 MW in 2011 from 2.388 MW in 2001. This equals a CAGR of 13.4%. The potential of biomass sources in Iran is estimated to be 132 million ton (oil equivalent) in the form of agricultural and forest wastes, livestock wastes, municipal wastes, sewage and industrial wastes. Taking into account the usual amount of biogas yield from agricultural wastes, animal wastes, municipal wastes and industrial and municipal wastewater and with good safety factor, biogas in Iran will generate about 16146.35 million m^3 which is approximately 323 petajoule (10^{15}) of energy. This paper investigates the potential of biogas production from biomass sources in Iran and presents the energy carriers, examples of biogas production, applications and quantitative potential of different sources in Iran.

Contents

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1. Introduction

Limitation of fossil resources, their non-renewability, increasing petroleum fuel prices, emissions from combustion of fossil fuels all cause energy policy makers and planners to focus on structural studies, to change the energy carriers, and move towards cleaner fuels. One of the best options in this regard is using the energy from biomass sources such as biogas. Biogas as one of the major sources of energy can be used directly to provide heating and electricity energy and is a good option to be used in internal combustion generators, micro-turbines, fuel cells and other power producing facilities as well [1,2]. Anaerobic digestion (AD) of organic wastes to produce methane would benefit society by providing a clean fuel from renewable feedstocks [3]. This could substitute fossil fuel-derived energy and reduce environmental impacts including global warming and acid rain [4,5]. Some of the advantages of biogas are 1—disposal of a huge amount of organic waste and recovering energy from it, 2—animal manure could also be utilized as fertilizer in agriculture, 3—national independence, 4—decrease of the odor problem, 5—economic and social development in rural areas, 6—provides new job opportunities [6,7]. It also has some disadvantages like 1—less suitable in cold and arid regions, 2—high construction costs relative to income of many potential users, 3—requires reliable feed source and 4—laborious operation and maintenance [8]. Biogas contains 50–70% methane and 30–50% carbon dioxide, as well as small amounts of other gases [9] and typically has a calorific value of 21–24 MJ/m^3 [10]. Relative biogas production rates and methane yield from solid organic waste is shown in Table 1. Biogas burns with a clean, blue flame and stoves have been considered as the best means of exploiting biogas in rural areas of developing countries [11]. Some researchers have worked on the potential of biogas production as shown in Refs. [12–25]. In 2012, about 194.8 million ton of renewable energy was consumed in the world and about 0.1 million ton was consumed in Iran [26]. To increase the biogas yield Mohseni et al. [27] used separated carbon dioxide as a component to produce additional methane through the well-known Sabatier reaction. In such a process, the carbon could act as a hydrogen carrier of hydrogen originating from water electrolysis driven by renewable sources. Zheng et al. [28] have worked on biogas production with two different approaches; (1) increasing corn stalk used by improving anaerobic fermentation technology; and (2) enhancing biogas productivity by optimizing fermentation conditions. Their results showed that the rate of biogas production was higher (78.4%) when cattle dung was used as a substrate than when crop residues were used. Heat preservation measures effectively enhanced the biogas production rate (12.3%). In a research Cesaro et al. [29] used sonolysis to enhance biogas production from anaerobic co-digestion. The results showed that the sonolysis could significantly improve the solubility of organic solid waste, thus allowing higher biogas production from anaerobic treatment of sonicated substrates. After 45 days, the biogas produced during anaerobic co-digestion tests for the sonicated mixture was 24% higher than the untreated one. Gueguim Kana et al. [30] used Artificial Neural Network (ANN) coupling Genetic Algorithm (GA) to model and optimize the biogas production. Evaluation of the optimal profile gave a biogas production of 10.280 l, thus an increase of 8.64%, and an early biogas production initiated on the 3rd day of fermentation as opposed to the 8th day in the non-optimized system. Thorin et al. [31] optimized the performance of biogas production plants by using pretreatment, membrane filtration of the re-circulated process of water and neural networks. The results indicated a potential to increase the biogas yield from the process up to 30% pre-treatment of the feed and including membrane filtration in the process. Neural Networks have the potential to be used for prediction of biogas production. Lantz [32] used biogas produced from manure in Sweden as fuel for the CHP system to generate combined heat and power. The results from his study could be utilized by policy makers when implementing policy instruments considering biogas production from manure as well as the companies involved in production and utilization of biogas. The effect of manure-screening on the biogas yield of dairy manure was evaluated in batch digesters under mesophilic conditions (35 °C) (Mashad and Zhang [33]). The predicted results from the model showed that

Table 1
Relative biogas production rates and methane yield from the co-digestion of solid organic waste.

Substrate	Co-substrate	Biogas production rate (l/d)	Methane yield (l/kg VS[a])	References
Cattle excreta	Olive mill waste	1.10	179	[12]
Cattle manure	Agricultural waste and energy crops	2.70	620	[13]
Fruit and vegetable waste	Abattoir wastewater	2.53	611	[14]
Municipal solid waste	Fly ash	6.50	222	[15]
Municipal solid wastes	Fat, oil and grease waste from sewage treatment plants	13.6	350	[16]
Pig manure	Fish and bio-diesel waste	16.4	620	[17]
Potato waste	Sugar beet waste	1.63	680	[18]
Primary sludge	Fruit and vegetable waste	4.40	600	[19]
Sewage sludge	Municipal solid waste	3.00	532	[20]
Slaughter house waste	Municipal solid waste	8.60	500	[21]

[a] VS: Volatile Solids.

adding food waste into a manure digester at levels up to 60% of the initial volatile solids significantly increased the methane yield for 20 days of digestion. One major problem in biogas production is upgrading the biogas, i.e., the removal of CO_2 from CH_4. Scholz et al. [34] used membrane technology to transform biogas into bio-methane. They investigated the membrane materials, gas permeation modules and their respective operation as well as gas permeation processes for biogas upgrading. Thorin et al. [31] by optimizing the performance of a biogas production plant found that residues from biogas production can be used as fertilizers but that the emission of N_2O from the fertilized soil is dependent on the soil type and spreading technology. Also the results indicated a potential to increase the biogas yield from the process up to 30% with pre-treatment of the feed and including membrane filtration in the process. Some researchers did a study on biogas production, technologies and applications [35–60].

Four main animal husbandries in Inner Mongolia Autonomous Region (IMAR), Chiefeng, Erdos, Huhhot and Xilinguole were detected to survey the biogas utilization in large-scale farms and assess the potential of biogas power generation and comprehensive utilization [61]. The formal and legal requirements as well as the support system for building agricultural biogas plants in Poland have been presented in Ref. [62]. There are currently 24 agricultural biogas plants operating in Poland. It has been calculated that in Poland the theoretical annual biogas potential for cattle slurry is 3646 million m^3, for pig slurry it is 2581 million m^3, for poultry manure it is 717 million m^3, from maize after seed harvest it is 1044 million m^3, and from municipal waste biofraction it is 100 million m^3 of biogas [62].

The regional distribution of household biogas and large and medium-scale farm biogas projects was analyzed by the index of popularization rate. The results showed that Chinese household biogas has an obvious geographical difference in popularization rate and can be divided into five zones: high popularity in southwest areas, steady development in central areas, rapid growth in western areas and low popularity in northeast and eastern coastal areas [63].The multi-scale design of membrane-based gas separation is analyzed in detail. Membrane materials, gas permeation modules and their respective operation as well as gas permeation processes. For biogas upgrading is investigated. Membrane-based upgrading systems are an interesting alternative to conventional biogas upgrading equipment [64]. There are about 49 biogas plants in South Korea that are generally recognized as economically and technically unsuccessful due to lack of knowledge, deficient technologies and policies. Based on the general policy called “Green Growth”, the Korean government plans to establish a biogas market in South Korea in order to recover energy from organic waste [65]. With 20 centralized plants and over 35 farm scale plants, the digestion of manure and organic waste is a well established technological practice in Denmark. The current setback in biogas plants is mainly caused by a shift in energy and environmental policies and limited availability of organic waste [66]. The opportunities and constraints of biogas use in the Rungwe district of south west Tanzania was investigated in Ref. [67]. Results of this study showed that the demand for biogas (90%) among respondents is high and the energy policy as well as donor community favors the promotion of energy efficient technologies such as biogas [67]. The construction of biogas digesters has improved the family energy consumption structure, promoted the development of livestock breeding and farm production in the countryside [68]. An attempt at the techno-economic evaluation of the biogas-based pumping system in India has been made in Ref. [69]. The potential reduction in the amount of CO_2 released in the atmosphere due to the use of the biogas-based water pumping systems has also been taken into account in the estimation of economic benefits. The economic figures of merit such as discounted payback period, net present value, benefit to cost ratio and internal rate of return have been estimated [69]. The strategies to overcome barriers to the adoption of improved cooking stoves and small biogas digester technologies in Thailand have been investigated in Ref. [70]. Results from this study showed that the cumulative total energy consumption and corresponding emissions reductions during the period 2002–2030 by the improved cooking stove are 27,888 ktoe and 10,041 thousand ton of CO_2 equivalent, respectively. Regarding the small biogas digester, the cumulative total liquefied petroleum gas (LPG) consumption reduction and CO_2 mitigation are 5780.9 ktoe and 1548.8 thousand ton of CO_2 equivalent during the period 2002–2030, respectively. Results show that the traditional cooking stoves are successfully replaced (more than 20% per year). Regarding the small biogas digester, the biogas pool project (BPP) is implemented to resolve the oversupply of biogas [70]. The prospects of and challenges to the expanding of sustainable biogas energy in Poland have been investigated in Ref. [71]. It is revealed that agro-biogas is characterized by a unique feature of ‘negative net’ CO_2 atmospheric emissions. In regard to biogas energy systems it is stressed, that the cost of electricity from biogas is almost independent of the size of agro-biogas CHP power plants in the range of 0.2–5 MWe [71]. There are vast biomass resources in Zimbabwe that have good potential for biogas production by anaerobic digestion [72]. Within the transport activity sector, on road vehicles and agricultural machinery require around 2 Mtoe of energy in France. The anaerobic digestion of farm waste could roughly cover these needs [73]. Since anaerobic digestion is available to each farmer in a different way depending on the location and the scattering of the primary sources, it is essential to clarify the best conditions adapted to local situations to treat the targeted residues and make this information accessible to farmers. In particular the possibility of co-digestion seems to be very attractive for farmers who will be able to treat their own waste together with other organic substrates [74]. Pakistan spends almost 7 billion US $ on import of fossil fuels annually to congregate its energy needs. The renewable and sustainable energy resources are the best substitutes for the conventional fuels and energy resources. Pakistan takes the opportunity to have almost 159 million animals producing almost 652 million kg of manure daily from cattle and buffalo only that can be used to generate 16.3 million m^3 of biogas per day and 21 million ton of bio fertilizer per year [75]. The state of the biogas sector has been investigated in Ref. [76]. Nepal is one of the least developed countries with the vast majority of people involved in subsistence agriculture. The use of biogas technology in Nepal has benefited the country by improving health, environment, economy and energy conservation [76,77]. The GIS model was used to help determine the optimal sites for installing anaerobic digesters in Poland. The focus was placed on animal manure and co-substrates such as crop silage [78].

2. Biogas in the world

Manure and wastewater have been used for energy purposes for millennia, with the earliest records of biogas utilization dating back to about 2000 years ago in Asia. By the 1800s, China and India burned biogas for heating water. Improved technology boosted production before the First World War was already feeding bio-methane into the gas distribution network in the 1920s. Since 1949, compressed biogas is being used as car fuel. After the Second World War, comparatively cheap oil made biogas unprofitable and many plants were closed down until the oil crisis in the early 1970s. As oil got costlier in the aftermath, biogas for heating, electricity or CHP became popular and production started to grow again.

Technological improvements over the last decades and efforts to reduce greenhouse gas emissions are currently giving more weight to biogas in the energy mix. While biogas is produced in most countries, there are also some truly global leaders, with three countries responsible for most of the world's production. By far the largest market is the USA with more than 50 TWh. Germany and the UK are also significant producers, although even their combined output is below the USA. Global biogas installed capacity is expected to achieve moderate growth over the next 12 years, reaching 22.040 MW by 2025 and making a compound annual growth rate (CAGR) of 7.2%, a recently published analysis by Global Information Inc (GII) showed. The world biogas market has grown considerably between 2001 and 2011, with installed capacity expanding to 8.377 MW in 2011 from 2.388 MW in 2001. This equals a CAGR of 13.4%. As it mentioned, the leading nations in the global biogas market are Germany, the US and the UK, accounting for over 50% of the total installed capacity worldwide. Germany has 28.1% of the world's installed biogas capacity, followed by the US with 19.7% and the UK with 15.5%. Germany's biogas sector accounted for some 3.7% of the country's total renewable power capacity in 2011 and the total biogas installations in the country reached 2.247 MW between 2001 and 2011. US landfill gas capacity contributed 15% to the country's total bio-power generation in 2011. In Britain, biogas from landfills made up 33.7% of total installed bio-power capacity in 2011. Sewage sludge gas also contributed 6% to the UK's total bio-power installed capacity in 2011. Global biogas capacity is expected to reach 22,000 MW by 2025. European biogas electricity production in 2006 was 17,272 GWh per year, of which 7338 GWh was by Germany alone. Biogas now represents 1.2% of the annual production of electricity and nearly 10% of renewable energy, with an installed power close to 1500 MW [97–118]. Production of biogas in selected countries and the Nordic region has been indicated in Fig. 1.

The market for renewable energy grows in excess of 30% per year. In recent years, the world market for biogas plants and AD equipment has increased at rates of 20–30% annually, depending on the country. In the U.S. Energy Information Administration's (EIA) 2010 global energy outlook, the total world consumption of marketed energy is predicted to increase by 49%, or 1.4% per year up to 2035. Biogas is gaining traction as a versatile energy carrier with significant potential to meet the growing demand within the power, heat, fuel and chemical markets. According to a new report from Pike Research, this fast growing market reached \$17.3 billion in the global revenue in 2011 and will nearly double by 2022, hitting \$33.1 billion in that year (Fig. 2). Global installed production capacity is now more than 800 billion ft^3 per year, representing nearly 14.5 gigawatt (GW) of installed distributed and grid-scale renewable generation capacity, with at least 11 billion ft^3 per year of production capacity expected to come online worldwide by the end of 2012. Renewable natural gas (RNG) is a growing segment within the diverse biogas landscape [79–96].

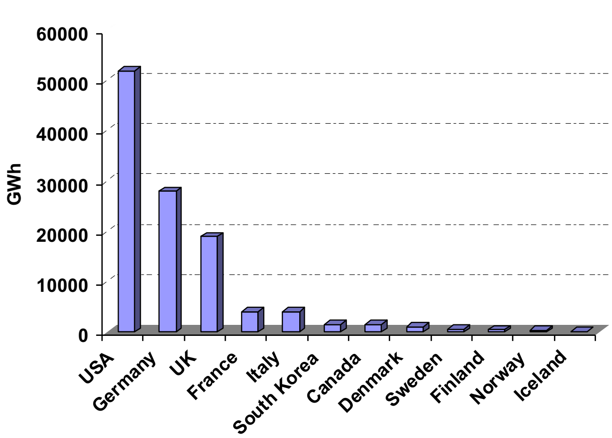

Fig. 1. Production of biogas in selected countries and the Nordic region. *Source*: UN Data, December 2009.

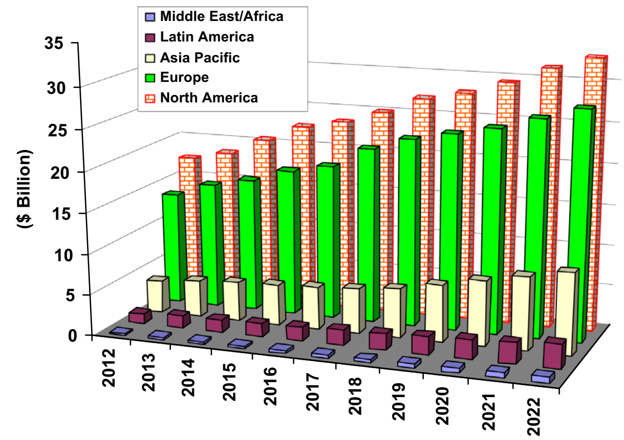

Fig. 2. Biogas market value by region, world markets. *Source*: Pike Research's report.

Table 2
Components of biogas.

Component	Percent
Methane (CH_4)	50–75%
Carbon Dioxide (CO_2)	25–50%
Hydrogen (H)	5–10%
Nitrogen (N_2)	1–2%
Hydrogen Sulfide (H_2S)	Traces

3. Biogas process and techniques

Anaerobic digestion is the degradation of organic material by microbial activity in the absence of air transforming it into biomass and biogas, a mixture of methane (CH_4), carbon dioxide (CO_2) and some trace gases (Table 2). Biomass conversion paths and the anaerobic disintegration phases of organic substances have been indicated in Figs. 3 and 4 respectively.

The process (anaerobic digestion) is carried out in the following four stages:

(1) Hydrolysis: this describes the cleavage of a chemical compound through reaction with water. Thereby, a hydrogen atom (H) is added to one part of the split chain, while the remaining hydroxyl group of the water (OH) is added to the other. At this step, insoluble complex molecules such as carbohydrates and fats are broken down into short sugars, fatty acids and amino acids.
(2) Fermentation and acidification: fermentative bacteria transform sugars and other monomeric organic products from hydrolysis into organic acids, alcohols, carbon dioxide (CO_2), hydrogen (H) and ammonia (NH_3).
(3) Acetogenesis: the products from fermentation (organic acids, alcohols) are converted into hydrogen (H_2), carbon dioxide (CO_2) and acetic acid (CH_3COOH). To produce acetic acid, acetogenic bacteria need oxygen and carbon. For this, they use the oxygen dissolved in the solution or bounded-oxygen. Hereby, the acid-producing bacteria create an anaerobic condition, which is essential for the methane-producing microorganisms responsible for the next step.

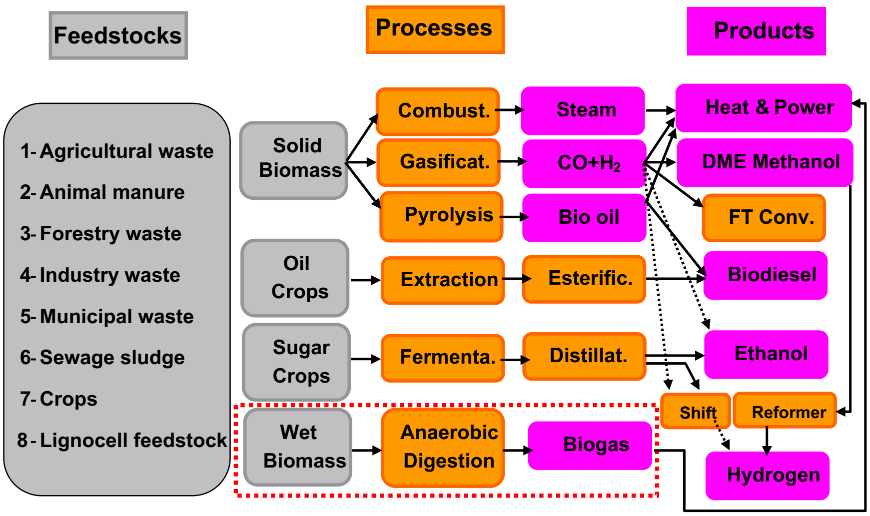

Fig. 3. Biomass conversion paths.
Source: IEA Energy Technology Essentials.

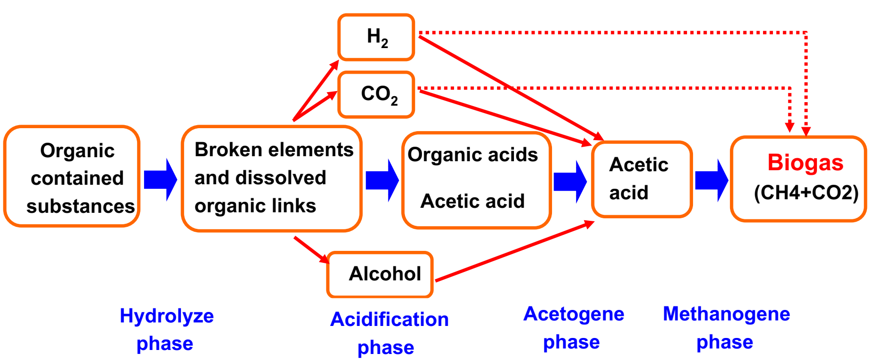

Fig. 4. The anaerobic disintegration phases of organic substances.

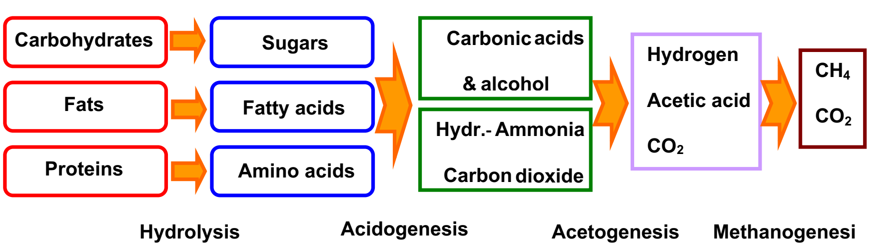

Fig. 5. Transformation stages in the anaerobic digestion process.

(4) Methanogenesis: methanogenic bacteria (methanogens), which are strictly anaerobic, transform the acetic acid, carbon dioxide and hydrogen into a mixture of methane (CH_4, 50–75%), carbon dioxide (CO_2, 50–75%) and varying quantities of nitrogen, hydrogen sulfide and other components. This mixture is called biogas [123,124].

To achieve this sequence of four steps, various bacteria (e.g. fermenting, acetogenic and methanogenic bacteria) need to work together [125].

Transformation stages in the anaerobic digestion process and schematic representation of the biogas value chain have been indicated in Figs. 5 and 6 respectively.

The stability of the process used and expectation of the quantities and qualities of the gas product, the effluent product are the important elements that combine to bring about technical and economic success. Since the methanogenic bacteria are strictly anaerobic, anaerobiosis should be strictly applied.

3.1. *The effect of temperature*

Like all biological processes, anaerobic digestion is very sensitive to temperature. Three temperature zones can be distinguished for which bacterial populations are effective:

– the psychrophilic zone for temperatures lower than 20 °C;
– the mesophilic zone for temperatures between 25 and 35 °C;
– the thermophilic zone for temperatures above 45 °C.

Above 70 °C, the usual bacterial populations are inactive. A drift in the temperature brings a modification of the bacterial populations; the variations best adapted to the conditions of the milieu taking the lead. Increasing the operating temperature of

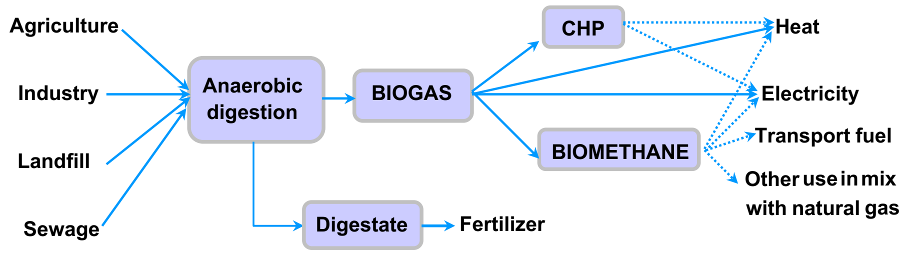

Fig. 6. Schematic representation of the biogas value chain.

Table 3
Contribution of different energy carriers in the energy sector of Iran [100].

Year	2005	2006	2007	2008	2009	2010	2011
Household, public, commercial							
Petroleum products	25.78	24.55	21.90	21.07	19.84	17.48	15.50
Natural gas	62.07	60.66	63.79	66.20	66.38	68.66	69.51
Coal	0.02	0.02	0.02	0.02	0.02	0.02	0.02
Combustible renewable resources	0.44	3.17	2.85	1.28	1.34	1.29	1.32
Power	11.70	11.60	11.43	11.43	12.42	12.54	13.66
Total energy consumption	100	100	100	100	100	100	100
Industry							
Petroleum products	33.55	33.43	31.23	27.52	28.87	25	20.82
Natural gas	50.27	51.64	53.87	59.43	58.29	61.60	65.65
Coal	0.17	0.15	0.17	0.14	0.12	0/09	0.03
Power	16.01	14.78	14.73	12.91	12.72	13.30	13.50
Total energy consumption	100	100	100	100	100	100	100
Transport							
Petroleum products	99.75	99.22	98.75	97.53	95.83	92.93	88.29
Natural gas	0.23	0.76	1.22	2.43	4.12	7.02	11.65
Power	0.02	0.03	0.03	0.04	0.05	0.05	0.06
Total energy consumption	100	100	100	100	100	100	100
Agriculture							
Petroleum products	71.69	71.29	70.87	69.41	66.74	65.12	62.60
Natural gas	–	–	0.92	2.96	3.52	5.85	5.90
Power	28.31	28.71	28.21	27.63	29.74	29.03	31.51
Total energy consumption	100	100	100	100	100	100	100
Non-energy consumption							
Petroleum products	54.11	56.35	62.31	64.81	66.44	66.60	55.78
Natural gas	40.42	36.62	32.89	31.20	31.38	32.06	42.64
Power	5.45	7.03	4.80	3.99	2.18	1.34	1.58
Total energy consumption	100	100	100	100	100	100	100

Considerations: calculations are based on the average values of millions of barrels of crude oil.
(1) Include all other uses of electricity.

an anaerobic digestion installation is one method of adapting it to increase the substrate to be treated [122].

3.2. Effect of pH

For the process to work well the pH should remain close to 7.5 for liquid or solid manure; the system regulates itself with good buffer ability. For other substrates (whey, silage), it is necessary to monitor this parameter and, eventually, to intervene (by adding lime). In fact, at the time of the acidogenesis and acetogenesis phases, if the hydrogen formed is not used to produce methane with CO_2, the accumulation of hydrogen can block fermentation [122].

3.3. Dynamics of the bacteria populations

The temperature and pH play a major role. This especially affects the speed of multiplication of the bacteria populations. They develop, of course, in relation to the substrates present, but they are also eliminated with the effluent at the end of fermentation. In order to avoid the slowing down of the biological process when new substrates are introduced, an attempt must be made to fix the microorganism populations in the digesters or to recirculate the effluents to inseminate the entering substrates. The most advanced digester techniques pay close attention to this effect [122].

Fig. 7. Sheikh Bahai bath.

3.4. Mixtures of substrates or codigestion

The substrate mixtures give results that cannot be reduced to a simple rule of proportions since the organic wastes treated usually have a methanogenic potential between 170 and 740 l of CH_4/kg of organic matter. The mixture of substrates enables an increase in the energy production by treating the substrates which, alone, are more difficult to degrade. This is especially the case for fatty waste from agro-feed [122].

4. Production of biogas in Iran

As is clear from Table 3, combustible renewable resources have a very small share in the energy supply for the industry, transport and agriculture sectors and their only usage is in domestic, public and commercial sectors [100]. Since natural gas had a great contribution in providing the energy of domestic, public, commercial and industrial sectors (Table 3), the residential, commercial and industrial end-conserving contributions are more than half. The production of biogas (with properties similar to natural gas) can reduce the consumption of natural gas. Also by burning biogas in biogas plants combustion energy can be converted into electrical energy.

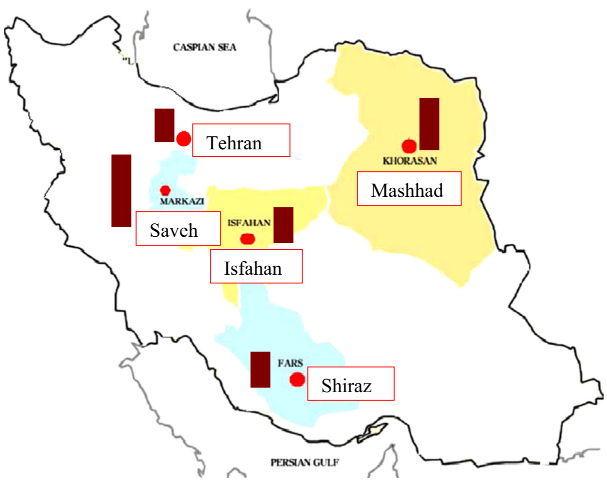

Fig. 8. Five biogas in operation plants in different provinces of Iran.

Fig. 9. The Shiraz biogas production system [97].

4.1. Production and application of biogas in Iran

Apart from the possibility of Sheikh Bahai bath in Esfahan which had been warmed up by methane produced from Isfahan city sewage, there are no other records for biogas production in Iran in ancient periods. The Sheikh Bahai bath building is attributed to Mohammed Hussein Amel [100,101], and a gas flame was directly used to warm up the water of the bath reservoir [102] (Fig. 7). During recent years, the first methane digester of Iran has been built in the village of Niaz Abad at Lorestan province in 1975. This unit's capacity was 5 m^3 and used cow manure obtained from the village cattle to provide the biogas for the bath in the village [103]. Later on the academic and research centers of Iran constructed and operated many pilot plants. Some of the examples are 1—Shiraz biogas plant; 2—Mashhad biogas plant; 3—Saveh biogas plant; 4—Isfahan biogas plant and 5—Tehran biogas plant (Fig. 8).

4.1.1. Shiraz biogas plant

Landfill gas, a gas of the anaerobic and stable methane phase, consists of 35–60% methane and 20–45% carbon dioxide. The gas composition changes over the years (CH_4 content drops). Shiraz biogas plant uses the biogas of landfill as fuel and is constructed over an area of1 ha and includes two biogas combustion engine-generator units with 500 kW capacities. This plant has an overall of 1060 kW capacity and with the ability to convert 4 million m^3 biogas into electricity. It consumes 740 m^3/h of biogas. This plant generates 7188.8 mWh of electricity per year. Because of increasing gas production and the huge volume of waste in Shiraz city, there are plans to develop at least 6 mWh [103,104]. Fig. 9 shows this system for biogas production. Fig. 10 shows the schematic of the Shiraz biogas production system.

4.1.2. Mashhad biogas plant

Approximately 1600–1700 ton of waste is produced per day in Mashhad city. A biogas plant with a nominal capacity of 650 kWh has been constructed in the old municipal waste landfill of Mashhad. This plant is capable of delivering 4 million kW to the network per year for 13 years. Annually more than 2 million m^3 biogas will be produced and used in this plant. Also it is estimated that around 20 thousand - ton of greenhouse gases will be reduced per year. An environmental

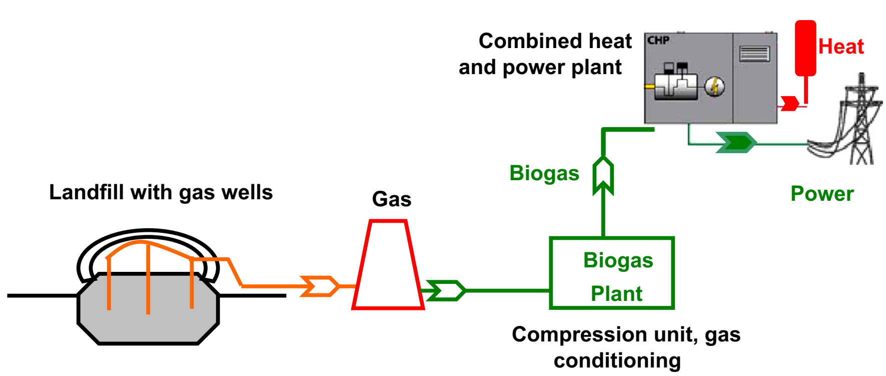

Fig. 10. The Shiraz biogas production system [97].

cost of 1 ton of methane is about 21 times more than that of carbon dioxide. Currently two units of this plant with 330 kW capacities provide electricity for 600 families in Mashhad. It is predicted that in the next stage, its producing capacity will increase to 1 MW. Also 2–3 ton of granular fertilizer produced in Mashhad compost manufacture helps to protect the environment and also helps the sustainable agriculture [103] (Fig. 11). This plant is the first electricity generation center in Middle East which uses landfill gas and started working in 2007. A process flow diagram of power generation on Mashhad landfill gas has been indicated in Fig. 12.

4.1.3. Saveh biogas plant

Saveh city in Markazi province is one of the industrial cities of Iran. The biogas project was started by the renewable energies department of Iran (SUNA) in 2005 in the industrial city of Kaveh. About 175,200 kg of municipal solid waste, 12,000 kg of slaughterhouse waste, 27,400 kg of refinery sludge and 13,700 kg of domestic sludge is fed to the plant (Fig. 13) [103]. Table 4 shows the products of the Saveh biogas plant. This plant is the first biogas reactor of Iran which generates energy from solid and liquid organic wastes.

The process of biogas generation in Saveh biogas plant is divided into three steps for the preparation of the bio-input fermentation and post-treatment of the residual material. At the start, the organic material is collected in a primary pit, and moved to the digester. The biogas produced in the digester is collected in a gas storage tank to ensure a continuous supply of gas, independent of fluctuations in the gas production. Finally, the biogas is fed into a gas engine. The process of biogas generation at Saveh biogas plant has been indicated in Fig. 14.

Fig. 11. Biogas plant of waste landfill in Mashhad (unit 1) [103].

4.1.4. Isfahan biogas plant

This plant with 1 MW capacity is the first unit of sewage biogas in Iran. As the authorities in biomass office of SUNA claim, more

Table 4
The products of Saveh biogas plant [103].

Product	Quantity
Produced gas (m^3/day)	6930
Plant power (kW)	606.3
Plant heat power (kW)	779.6
Liquid fertilizer (water production) (m^3/yr)	43,400
The electrical energy per year (kWh)	4,850,400
The heat energy per year (kWh)	6,236,800
Organic fertilizer with 50% moisture content (ton/yr)	6290

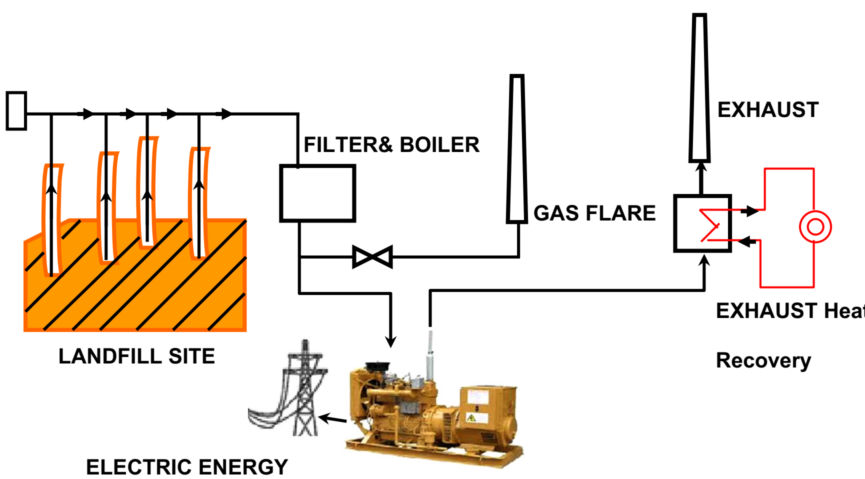

Fig. 12. Process flow diagram of power generation on Mashhad landfill gas.

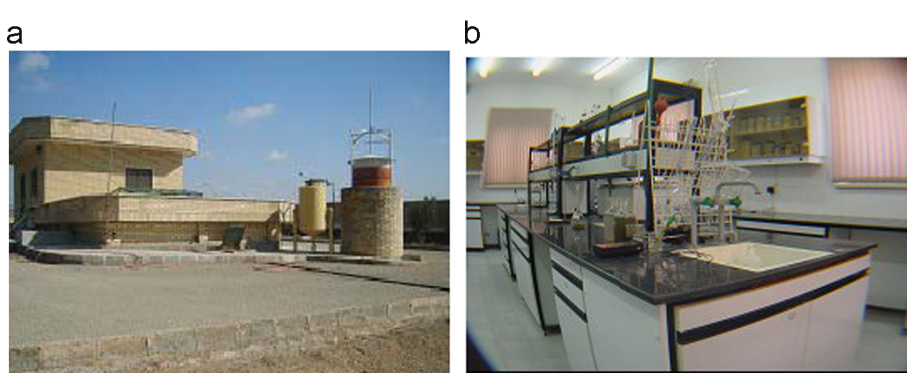

Fig. 13. (a) A view of the Saveh biogas plant and (b) laboratory of Saveh biogas plant [103].

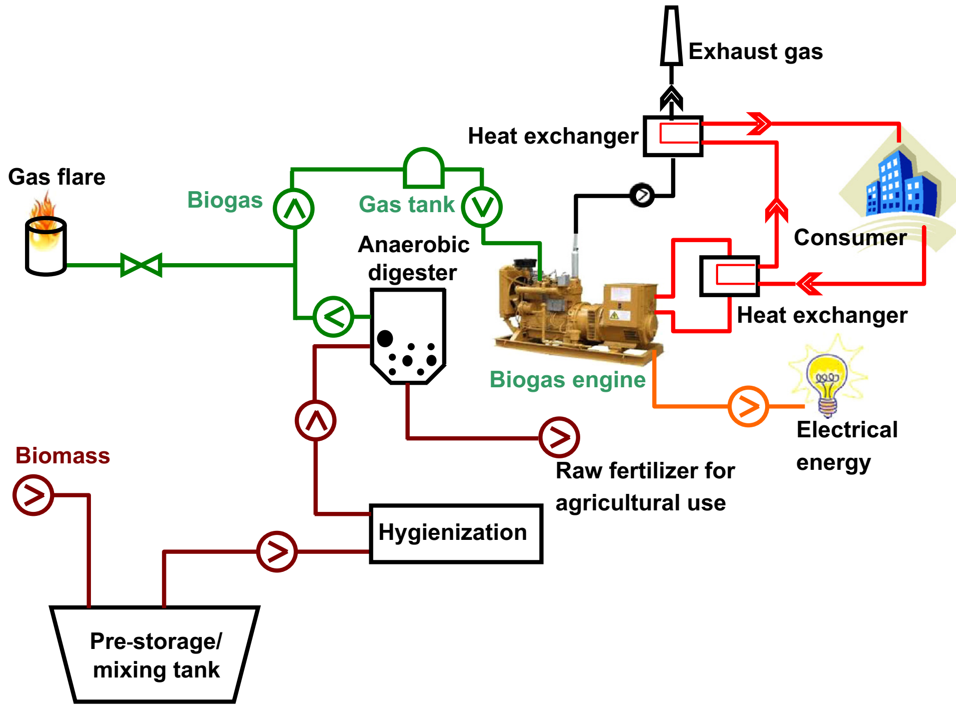

Fig. 14. The process of biogas generation at Saveh biogas plant.

Fig. 15. Biogas plant in sewage refinery of Isfahan.

than 7 million kWh electricity is added to the network by this plant [103] (Fig. 15).

4.1.5. *Tehran biogas plant*

A biogas plant of sewage refinery in south of Tehran with 5 MW capacity has been connected to the city's sewage lines in January 2011. Currently this plant produces 2 MW of electricity [103]. Sewage gas has a heating value of 6–6.4 kW/m^3 and fluctuating methane content due to its organic ingredients. Use of sewage gas to generate electricity in Tehran biogas plant has been indicated in Fig. 16.

4.2. *Potential of biogas resources in Iran*

Biogas sources in Iran are divided into 5 groups [103]:

(1) wastes: agricultural residue and related industries;
(2) municipal solid waste;
(3) municipal wastewater;
(4) animal waste;
(5) solid and liquid perishable industrial waste.

Biogas can be obtained from the fermentation of biomass. With different biochemical and thermo-chemical processes, all biomass resources have the potential to produce three forms of energy namely electricity, heat and biofuels that can be used in the domestic, industrial and transport sectors.

Iran has enough enriched sources of biomass. According to surveys conducted by the department of energy in 2002, the potential of biomass resources is 132 million barrel of crude oil equivalent which is dominant in agricultural and forest waste, livestock waste, municipal waste, industrial waste and sewage [103]. Table 5 lists the potential for biogas production from some of these sources.

4.2.1. *Agricultural and industries wastes and residues*

In the year 2010–2011, almost 75.4 million ton of crops have been harvested from arable land in Iran, from which 22.2 million - ton was grain (wheat, barley, corn), 716,000 ton was legumes (peas, beans, lentils, etc.), 10.4 million ton was industrial products (cotton, tobacco, sugar beets, oilseeds and sugarcane), 15.8 million ton was vegetables (potatoes, onions, tomatoes, etc.), about 8.2 million ton was melon, watermelon, and cucumber and 17.9 million ton was forage plants group (alfalfa and other forage plants) [107]. Table 6 presents the waste percentage of some agricultural products. If the average losses of these products are considered to be 30%, the amount of waste produced for 1 year is about 23 million ton [108]. If it is assumed that an average of 450 m^3 of biogas is produced from each ton of waste, about 10,350 million m^3 of biogas will be generated from agricultural wastes.

4.2.2. *Municipal solid wastes*

Biogas is created 2–6 months after burying wastes in landfills. This retardation time depends on the percentage of organic renewable materials in wastes, distribution of material within

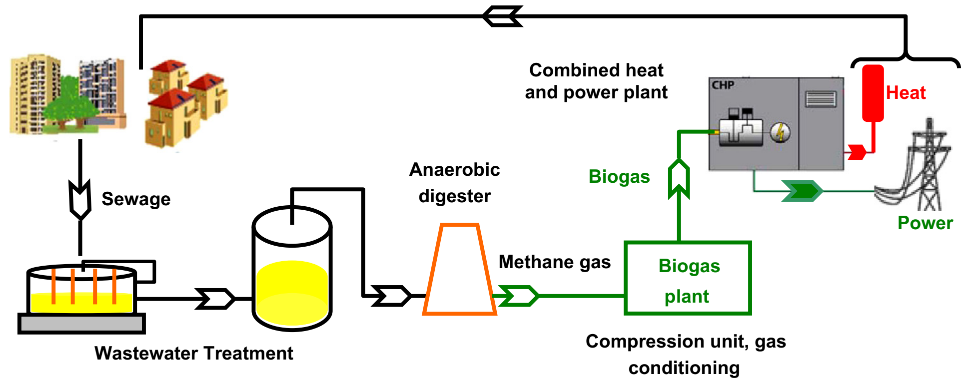

Fig. 16. Use of sewage gas to generate electricity in Tehran biogas plant.

Table 5
Potential of biogas production from various sources [104–106].

Material	Biogas produced from each ton of material (m^3)	Retention time (days)
Kitchen grease residues	1038	–
Cane	550	–
Vegetable waste	450	–
Wastewater	169.5	15
Municipal solid waste	420	20
Cow manure	307	15
Sheep droppings	200	20
Bird muck	350	20
Corn stalks	430	20
Barley stalks	460	18
Grass and fresh grass	480	20
Rice straw	400	24
Banana skins and waste	950	15
Potato skins and waste	900	15

– Not mentioned.

the landfill, the rate of water inflow into the landfill and ambient temperature [112]. Percentage of organic wastes in municipal solid wastes in Iran is about 75% while in the USA it is about 25% [113]. Using anaerobic digestion, most of the organic material in the waste is decomposed and biogas is produced by anaerobic bacteria fermentation. Due to the high energy content of food wastes (depends on the type of food 94–424 ml CH_4/dry weight), it will be useful to produce biogas out of these wastes. Stabilized materials can be used as fertilizers rich in nitrogen and phosphorus [114,115]. In Iran, for every person an average of 0.8 kg of waste is produced every day. About 45–50 thousand ton of wastes are generated per day in Iran and since 1 m^3 of biogas is obtained per 15 kg of municipal solid waste, 841 petajoule of gross energy can be generated from municipal solid wastes in Iran [103]. Quantity of wastes input to landfill in 2009 for cities with population above 250,000 people is given in Table 7.

4.2.3. *Municipal wastewater*

Urban and rural sanitation are major environmental pollutants. These wastewaters have significant potential and the best way to release this energy is anaerobic fermentation and production of methane gas which can be used for heating or to drive generators and generate electricity [116]. Annually 4.6 billion m^3 of municipal wastewater is produced in Iran [106]. In cities with a population of more than 100 thousand are considered refining their wastewater through the anaerobic process would yield, 107.8–245 million m^3 of biogas. If the aeration process is used, these values will be lower. For example, using the activated sludge process, the amount of biogas obtained from sludge digester will be about 20.9–107.8 million m^3.

Table 6
Loss percentages of some agricultural wastes [109–111].

Product	Loss percent	Product	Loss percent	Product	Loss percent
Wheat	31	Corn	38	Plum	5
Sugar beet	34	Grain	48	Pistachio	42
Potato	27	Barely	37	Date	24
Tomatoes	11	Banana	23	Pea	49
Watermelon	32	Apricot	1	Onions	16
Grapes	34	Strawberry	2	Melon	17
Apple	28	Pears	3	Cucumber	16
Peach	30	Cherry	30	Fig	35
Pomegranate	25	Orange	30	Tangerine	31
Lemon	26	Chino	26	–	–

Table 7
The quantity of input wastes in landfill in 2009, in terms of tons per day [103].

City	Amount of waste input to landfill (ton)	City	Amount of waste input to landfill (ton)
Tehran	6648	Boroujerd	100
Mashhad	1655	Khorramabad	300
Isfahan	1203	Dezful	151
Karaj	1164	Yazd	238
Tabriz	1070	Ahvaz	1080
Gorgan	207	Abadan	145.5
Sari	229.3	Kerman	308
Qazvin	339.3	Shiraz	900
Rasht	372.4	Bandarabas	295
Zanjan	258.3	Zahedan	196
Ardabil	338	Hamedan	578
Uroumieh	470	Qom	589.3
Sanandaj	213	Kashan	185
Shahre Qods	170	Arak	345
Eslamshahr	297	Kermanshah	100

4.2.4. *Livestock wastes*

Livestock wastes have considerable potential and can be used to produce biogas. Annually 74 million ton methane gas is produced from livestock manure in Iran [117]. According to the data released in 2011 in Iran, there are 24,659 animal husbandries with 2,747,124 cows [118]. There are approximately 72 million livestock in Iran [119]. Annually 74,946 ton of animal wastes are available in Iran from which 8668 million m^3 of biogas can be produced [120].

In 2001 about 852,814 ton of manure had been produced in aviculture of Iran [121]. If appropriate and enough biogas production stations are created in animal husbandries and rural areas it will be possible to use this huge amount of energy source.

4.2.5. Industrial wastes

Industrial wastes such as that from wood and food industries can also be used to produce biogas. For example: the wastes of wood industries, wastes of vegetable oil industries, waste of meat industries, wool and paper industries. Biogas from industrial wastewater is highly variable. This quantity depends on the type of industry, the type of wastewater refinery process and quantity of wastewater. For example, annually 81.5–279.4 million m^3 of biogas can be obtained from food industries (vegetable oil, alcohol, canned, fisheries, etc.) in Iran [103]. As is clear, approximately 16146.35 million m^3 of biogas (9175 million m^3 of methane) can be obtained just from these resources. Assuming that the heating value of methane is 36.7 MJ/m^3, this volume of methane is equivalent to 3.367×10^{17} J of energy.

5. Conclusions

Biogas is one of the renewable energies that in addition to energy production has the ability to produce agricultural fertilizers, increase public health level, is useful in disease control and creates a perfect solution for solid waste disposal. Global biogas capacity will reach 22,000 MW by 2025. European biogas electricity production in 2006 was 17,272 GWh per year, of which 7338 GWh was by Germany alone. Biogas now represents 1.2% of the annual production of electricity and nearly 10% of renewable energy, with an installed power close to 1500 MW. Global biogas installed capacity is expected to achieve moderate growth over the next 12 years, reaching 22.040 MW by 2025 and making a compound annual growth rate (CAGR) of 7.2%. The world biogas market has grown considerably between 2001 and 2011, with installed capacity expanding to 8.377 MW in 2011 from 2.388 MW in 2001. This equals a CAGR of 13.4%. The potential of biomass sources in Iran is estimated to be 132 million ton (oil equivalent) in the form of agricultural and forest wastes, livestock wastes, municipal wastes, sewage and industrial wastes. Taking into account the usual amount of biogas yield from agricultural wastes, animal wastes, municipal wastes and industrial and municipal wastewater and with good safety factor, biogas in Iran will generate about 16146.35 million m^3 which is approximately 323 petajoule (10^{15}) of energy. Iran is among the countries which have vast resources for biogas production. Despite high biogas potential and simple technologies of generators and reactors of biogas, unfortunately, the use of these resources in the country is limited. Due to administrative problems and lack of proper and efficient operation available units in this sector do not have efficient output. So it means that more attention and research is needed in this field.

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